

ROUTE I-80 PAVING EXPERIMENT

**A Comparative Study of Thick-Lift And
Standard Bituminous-Stabilized Base Construction**

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Equipment Committee

NEW JERSEY DEPARTMENT OF TRANSPORTATION

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ABSTRACT:

A study undertaken by the Department's Equipment Committee to determine the comparative levels of density and riding quality achievable on a full-scale project using thick-lift and conventional multiple-lift methods for constructing a bituminous-stabilized base is reported.

Six lane-miles of Route I-80, Section 1M constructed using a paver equipped with ski reference automatic grade controls and a single (4-inch) lift of bituminous-stabilized base is compared to an equal length of pavement constructed using manual paver controls and conventional (two 2-inch) base course lift thickness.

An analysis of core air voids confirms that the Department's standard compaction system (3-wheel breakdown, tandem finish) will produce significantly higher base course densities when single rather than multiple lift base construction is employed.

The potential for a relatively greater production rate for thick-lift construction was not realized on this project, with the hourly tonnage placed being controlled by material supply rather than construction method.

Pavement smoothness measurements obtained with a roughometer and rolling straight-edge both indicate that the average level of riding quality achieved on the finished pavement of the test and control roadways each merit a "poor" riding quality rating. The application of automatic grade control systems thus must be accompanied by an overall observance of good construction procedures to ensure the achievement of an acceptable level of riding quality. At the level of the bituminous-stabilized base, greater relative roughness for the thick-lift operation was observed to result in part from the construction being conducted as a basically stop-and-go operation.

It is recommended that subject to certain limitations, the single-lift construction technique be permitted. The suggested restrictions require the use of a stone mix base, high-type automatic grade controls, a maximum lift thickness, and a minimum rate of material supply. This latter restriction is felt to be particularly important since it will assist in minimizing the intermittency of thick-lift paving while maximizing the potential for increased production and thus possibly lower bid prices.

KEY WORDS:

bituminous pavement; multiple and thick-lift paving methods; density; ski; pavement riding quality; automatic grade reference systems; bituminous base, binder and top courses; roughometer and rolling straightedge; construction procedures.

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NEW JERSEY DEPARTMENT OF TRANSPORTATION

EQUIPMENT COMMITTEE

ROUTE I-80 PAVING EXPERIMENT

I. Introduction:

Research by a number of agencies has indicated that the construction of bituminous stabilized base course in a single, thick lift rather than in multiple thin lifts can result in a more economical, higher quality product (i.e., a base course of greater, more uniform density).

In New Jersey, an investigation of relatively short thick lift test sections constructed on several projects confirmed the finding of an improved density for single lift construction reported by others. On certain of these study sites, however, a comparatively rough riding base course surface was also obtained.

This report presents an analysis of the bituminous base density and riding quality achieved on a large-scale, thick lift paving experiment undertaken under the sponsorship of the Department's Equipment Committee. The data presented herein consists of density measurements made by the Materials section, rolling straightedge and roughometer data collected by Research personnel, together with observations made by Construction personnel concerning paving equipment and techniques.

II. Description of Project:

The test of thick lift paving was conducted on Route I-80, Section 1M, a six lane divided facility approximately two miles in length located near Netcong, Sussex County.

The subject pavement section consists of 4 inches of bituminous stabilized base (stone mix) placed on a macadam base, and topped with 3 inches of FA-BC-2.

The experiment consisted principally of comparing the density and riding quality obtained on the bituminous stabilized base of the eastbound roadway -- placed in one full-depth lift using an electronically controlled paver -- to that of the westbound roadway, placed with a conventionally controlled paver in standard (2") lift thickness.

Apart from the requirements for single-lift base construction and electronic grade control for all courses, the construction of the eastbound roadway differed from that of the westbound in that the contractor (Tri-County Asphalt Corp.) was allowed to extend the placement and finish of mats beyond the usual 500 feet to a maximum of 1500 feet, or for such distance that the materials at the longitudinal joint would be maintained at not less than 150°F. This longer mat length was permitted in an attempt to minimize the recognized difficulty in achieving a smooth ride on a pavement containing numerous transverse joints. Additionally, the method of payment for the various courses of bituminous material of the eastbound roadway was changed from a square yard to tonnage basis, again with a view to obtaining an improved ride (i.e., correct for deficiencies in the preceding course by permitting slight variations in the thickness of a mat under construction to be made without penalty).

The same compaction equipment and rolling procedures were used for both roadways: a 10 ton 3-wheel roller imparting one breakdown pass and a 10 ton 2-axle tandem drum roller applying as many finishing passes as required to remove ridges.

It should be noted at the outset that, due in part to financial constraints, the described experimental design was adopted by the Equipment Committee as a compromise to enable the study to be undertaken. It is obviously impossible to completely isolate the sources of roughness in this four factor experiment (i.e., two base course lift thicknesses by two types of paver control) when only two measurement comparisons are possible (i.e., the roughness of the east versus the westbound lanes).

III. Observations Concerning Construction Equipment and Techniques:

1. General: Prior to beginning the work of this project, the contractor purchased a new Cedarapids crawler mounted asphalt paver. This equipment was subsequently used for all eastbound paving and was used alternately with a Barber Greene paver in placing the westbound lanes. In the westbound roadway, the use of the Cedarapids paver predominated (80-85% of total paving).

At the outset of thick-lift paving, the Contractor's field force had very limited experience with the new paver and its associated automatic controls as well as with thick-lift paving techniques.

2. Functioning of Automatic Controls: Automatic grade control was accomplished by using a mechanical follower which senses a grade reference alongside the paver and sends compensating signals to a servomechanism controlling the screed. On this project, two types of grade sensing devices were used: a 30-foot ski and a 10-inch matching shoe.

The 30-foot ski was primarily used during the initial pass of the paver and rested directly on the macadam base course. When used for adjacent passes, the ski rode either on the macadam base or on the previously compacted mat. When the 10-inch shoe was used, it was employed as the referencing system for abutting lanes. In such instances, the matching shoe rode on either the compacted or uncompacted portion of the mat. It is felt that the ski worked well in both its applications. The matching shoe required more attention. When the matching shoe was used according to the manufacturer's recommendation -- i.e., riding on the uncompacted portion of the mat -- an irregular reference was provided, the irregularity being due to roller marks, footprints and spillage. The compacted portion of the mat thus provided a much smoother reference for the matching shoe.

Automatic cross-slope control was provided by a control device attached to a beam between the paver screed arms. The effectiveness of this control device in maintaining the desired slope was determined by periodic visual checks of a slope-meter (level) provided on the main frame of the paver.

When the automatic feed control was operating properly, this control provided a continuous flow of material to the spreader screws at a rate appropriate for the lift thickness being placed. By properly controlling material flows, variable pressures against the screed and associated detrimental effects on the riding surface of the mat were eliminated. Unfortunately, various mechanical problems did not permit the continuous use of this control.

3. Paver Operation: Initial paver speed for thick-lift paving was 56 fpm. At this high speed, the slat conveyors could not move the

material from the hopper to the spreader screws fast enough to enable a continuous forward motion to be maintained; consequently, the paver was forced to stop at approximately 10-foot intervals to feed material and at approximately 30-foot intervals for truck unloading. These frequent stops resulted in 1/8 to 1/2-inch deep screed marks in the surface of the mat. The severity of these deviations occasionally was increased as a result of an unloading truck backing into the paver. While surface defects resulting from stop-and-go operation were present on all courses, they were most prevalent during the thick-lift operation. Straightedge and stringline checks made before and after compaction indicated that rollers did not eliminate these deviations. However, after the head raker was instructed to smooth screed mark ridges, this type of deviation was greatly reduced.

As thick-lift paving operations progressed, it became apparent that proper mat placement could not be achieved with the original paver equipment. By experimenting with paver speeds after the addition of so-called "speed-up sprockets", a feed rate compatible with continuous forward motion of the paver was obtained. At a reduced paver speed of 20 fpm, the number of paver stops was greatly reduced in comparison to the previous 56 fpm rate. Significantly, the 20fpm paver speed was found to be consistent with material supply to the project and did not reduce production.

Another procedure which was very successful in reducing stop-and-go operation and associated surface defects involved slowing the paver during material resupply. That is, during the time that a new truck was backing into the unload position, the operator advanced the paver at creep speed by placing the machine on idle. When this method was used, the screed vibrators shut off, creating the impression that the volume of material at the screed

had increased. However, after various checks, it was determined that the slowdown during unloading did not introduce any deficiencies into the mat.

During the thick-lift paving, it was thought that an optional two-speed conveyor transmission would correct the feed condition. However, due to problems between the contractor and paver manufacturer, such a transmission was not installed on the paver until the thick-lift on the I-80 mainline had been completed. When the modified paver was later used on thick-lift paving on Route 206, it was found that continuous forward motion could not be accomplished unless speed was increased from 20 to at least 36 fpm; the reverse of the experience on the I-80 mainline.

4. Mat Lengths: While the contractor was permitted to extend the placement and finish of the bituminous mats on the east-bound roadway for as much as 1500 feet in order to reduce the number of joints, in only one case was a mat of this length actually achieved. Due to project conditions (e.g., material supply and temperature), the required 150°F minimum temperature could not be maintained in mats longer than 700-800 feet.

5. Overall Operation: Many factors were observed to affect the riding quality achieved on this project: the workmanship of the paving crew and truck drivers; various paver adjustments, and on the Cedarapids in particular, the positioning of the pull points; settings on the vibrators; material temperatures from the plant; asphalt plant production and delivery; and spillage in front of the paver. The importance of properly functioning equipment and a thorough knowledge of the paver and the associated automatic controls in particular cannot be overstressed.

The roughometer and rolling straightedge equipment gave very valuable and rapid surface smoothness data such that corrective action could be attempted during the progress of the work. It is felt that it would be very beneficial for the Department's paving inspection crew to have a rolling straightedge available to them during construction so that rapid checks of the previous day's construction might be made.

Apart from the riding quality aspects of the paving operations, an additional factor of concern was production rates. Previous trials by the Department indicated that the single-lift paving would be capable of placing material at nearly twice the rate (tons/hour) of the double-lift operation. Unfortunately, this capacity for increased production was not realized on the I-80 project. Paver difficulties and a limited material supply caused the thick lift paving to exhibit no improvement in production over the double-lift method; the observed average paving rate for both modes of construction being approximately 100 tons per hour.

IV. Density Evaluation

1. Nuclear Density Measurements: During the planning stages of the Route 80 paving experiment, the contractor expressed concern as to the roller coverages needed to achieve adequate compaction of the thick-lift base. The coverages used had to be sufficient to densify the base to below the specification air voids limit of 10%.

Based on previous tests, it was expected that the compaction effort could probably be the same as that employed in constructing a normal two-inch thickness of base. However, to provide firm guidance in this area, it was agreed to make a series of preliminary density measurements at the start of thick-lift paving. It was judged that one could be fairly confident that a given compaction effort was adequate if the average of ten density measurements indicated a mean air voids level of not higher than 7%.

A nuclear gauge was selected as the density measurement device in order to afford almost instantaneous density evaluation. In addition, to insure the greatest possible degree of accuracy with the nuclear equipment, a correlation was established between nuclear and standard core densities prior to starting the deep lift work.

It was determined that a 6.7lbs/ft^3 correction factor had to be added to a nuclear density measurement to equal a corresponding core density value.

The thick-lift construction started with the contractor using the standard compaction sequence employed in paving a normal two inch course of base (1 pass or 2 coverages of a 3-wheel roller followed by

tandem finish rolling). Ten nuclear density measurements on this initial paving work indicated an average air voids level of 6.0%, well below the prescribed 7.0% limit. Accordingly, the contractor decided to construct the remainder of the deep lift section with the standard compaction sequence. It is worth noting that a subsequent check of core densities from this initial paving area revealed an actual air voids level of 5.5%.

2. Final Core Densities: Following completion of pavement construction, a total of 87 cores were successfully removed from the mainline roadway for laboratory evaluation of percent air voids. A copy of the Specific Gravity and Air Voids Content Report for the stabilized base is included in the Appendix. Pertinent information extracted from this report is summarized in Table 1.

<u>Table 1</u> <u>Summary of Core Air Voids</u> <u>for</u> <u>Bituminous-Stabilized Base</u> <u>Multiple Lift Construction (Westbound)</u>			
Portion of Base Course	Number of Cores	Average Air Voids (%)	Standard Deviation of Air Voids (%)
Top 2 inches	45	8.8	1.1
Bottom 2 inches	45	8.5	1.3
Total Course	45	7.9	1.0
<u>Thick-Lift Construction (Eastbound)</u>			
Top 2 inches	42	6.3	2.5
Bottom 2 inches	42	7.3	2.1
Total Course	42	6.1	1.6

The summary data reveals that the thick-lift mode of construction achieved an air voids level within the stabilized-base nearly 2% lower (6.1% versus 7.9%) than that produced by multiple lift paving. A statistical t score test performed at the 95% confidence level indicates that the observed difference is both real and significant. This finding is in complete agreement with the results of the Department's previous trials of deep lift construction. The ability of the deep lift paving technique to achieve a higher degree of densification is generally attributed to the better heat retention properties of thick layers of bituminous material. Temperature measurements on the Route 80 project established that the rate of temperature loss for the 4 inch lift of bituminous base was only 1/3 to 1/2 that of the 2 inch base.

Another important pavement characteristic of concern in this study was density uniformity. The data of Table 1 shows that both modes of construction produced a fairly uniform voids condition from top to bottom within the base course. This is a typical condition for a pavement course constructed by the deep lift method, but somewhat unusual for multiple lift pavement. Historical data has shown that the multiple lift technique cannot be relied on to always produce the same degree of densification in each of its lifts.

The variation of base density from station-to-station along the roadway was an additional factor of prime interest to the Equipment Committee. The standard deviations for base course air voids given in Table 1 serve as a quantitative measure of this factor. If past projects can be used as a means of predicting current conditions, one should expect the air voids

of an average bituminous base to have a standard deviation of approximately 1.5%. The standard deviations (total course) for both the multiple and thick-lift bases of the Route 80 experiment compare quite favorably with this figure. The thick-lift base does, however, have the larger of the two standard deviations.

The observed difference in density variability (significant at the 95% confidence level) is believed to have resulted from certain differences between the two paving methods. In multiple-lift construction the paver was stopped to accommodate each change in material supply trucks. For thick-lift paving, in order to avoid excessive screed depressions in the mat, the material resupply was often accomplished with the paver moving at creeping speed. Unfortunately, at such low speeds the screed vibrators shutoff and ceased to provide an initial compaction to the mat. As a consequence of this condition, it is estimated that as much as 1/10 of the thick-lift base did not have benefit of initial screed compaction. Since screed compaction is normally credited with achieving a significant portion (70 to 80%) of final mat density, the non-uniform use of the screed probably caused increased density variability along the base.

General deficiencies in material supply may be another factor contributing to the larger variation of density in the single lift pavement. That is, for continuous operation at a given paver speed, the thick lift method required twice the amount of material used in normal thin lift paving. This requirement unfortunately was not satisfied, causing the thick-lift paving to be extremely more intermittent than the multiple-lift operation. Such intermittency results in increased variability of laydown temperatures and, possibly, increased variability in final mat density.

V. Riding Quality Evaluation:

1. Description and Interpretation of the Output of the Roughometer:

The BPR roughometer consists basically of a test wheel mounted on a towing frame thru two leaf springs and calibrated damping devices. As it is towed along the roadway at 20 mph, the test wheel deflects with respect to the frame in proportion to the roughness of the road. The mount of differential movement between the test wheel and frame is measured and recorded as the "Roughness Index" in inches per mile.

Perhaps the most widely applied criteria for the interpretation of roughometer data is the following, developed by the Federal Highway Administration from a 580 mile survey of rural interstate mileage in 17 states:

FHWA Roughness Criteria

(Wearing Surface of Flexible Pavement)

<u>Roughness Index</u>	<u>Adjective Rating</u>
Below 54 inches/mile	Outstanding
54-66	Excellent
66-82	Good
82-102	Fair
Above 102	Poor

Based on data obtained to-date in an ongoing research project, it appears that the riding quality of New Jersey pavements is in general marginally acceptable in comparison to this criteria, with a roughness index of 100 or more being common.

Preliminary results indicate that the finished surface of stabilized base course typically ranges in roughness from 150 to 180 inches per mile, with the lowest project averages obtained to-date for this course being 120 to 125 inches per mile. It is interesting to note that given a roughness of 150 inches or more for a stabilized base course, a contractor would have to effect an approximately 25% roughness decrease in each of the succeeding two courses in order to achieve a final "good" riding quality rating according the FHWA criteria.

2. Description and Interpretation of the Output of the Rolling Straightedge: The rolling straightedge employed in this work consists of a 10 foot reference beam with a travel wheel mounted at each end and a movable indicator wheel attached at the midpoint. As the straightedge is pushed along the roadway, the magnitude and (high or low) nature of any deviation encountered is shown in 1/8" increments on an indicator dial, while the span of the deviation is shown by a full-length dye mark. The resultant magnitude and span length is recorded and summarized for 1/4 mile pavement sections.

An acceptable limit for straightedge deviations measured on a project -- in fact, the format in which such data should be considered -- is an unsettled question.

In this report, straightedge data is presented in three ways: as the simple number of deviations, the percent of defective length (i.e., total length of deviations per quarter mile divided by 1320), and the area of deviations (deviation length x magnitude). These latter two data presentations are employed in an attempt to take into account the severity of surface defects.

One criteria for evaluating the number of deviations is the present specification provision that the finished pavements shall have no deviations in excess of $1/8$ " in 10 feet. While this essentially zero defect provision seems impractical and is not in fact generally complied with, those (25 quarter-mile) pavement sections which have been measured with both the roughometer and rolling straightedge and which merit a "Good" or "Excellent" FHWA roughness rating have generally been observed to be defect-free. Pavements with relatively few deviations in excess of $1/8$ " have yielded "Fair" or "Poor" roughometer readings.

A number of agencies evaluate roughness by analyzing straightedge data in terms of the calculated "Percent Defective Length". In the FHWA Guide Specification, for example, that agency recommends a straightedge penalty schedule which provides for full payment if the percent defective length of the finished pavement is kept below 2%. Above 3.5% defective, a remove and replace or 40% payment provision is indicated.

In subsequent presentations of rolling straightedge data, an indication of the roughness occurring at transverse construction joints is made. Unlike the case of concrete construction, the limits over which bituminous pavement construction operations are influenced by the presence of a transverse joint are not well-defined. Decisions as to the extent to which joints introduce roughness thus obviously involve an exercise of judgement.

3. Roughness Results:

A. Stabilized Base Course: Table 2 presents comparative roughometer and straightedge data for six $1/4$ mile sections in each roadway on which successive measurements of base thru top course were made. On both

Table 2. Roughness Measurements of Successive Base, Binder, and Top Course

A. Thick-lift Construction: Eastbound Station 340+0 to 353+20

	INNER LANE						CENTER LANE						OUTER LANE					
	Inner Wheelpath			Outer Wheelpath			Inner Wheelpath			Outer Wheelpath			Inner Wheelpath			Outer Wheelpath		
	Base	Binder	Top	Base	Binder	Top	Base	Binder	Top	Base	Binder	Top	Base	Binder	Top	Base	Binder	Top
Roughness Index(RI)	221	156	140	184	134	134	206	176	117	178	149	134	217	157	131	192	172	137
No. of Deviations(N)	101	36	9	91	45	--	89	23	7	82	18	14	117	16	21	95	13	21
% Improvement(RI)		29%	10%		27%	0%		14.5%	33.5%		16%	10%		27.5%	16.5%		10.5%	20%
% Improvement(N)		64%	75%		50.5%	--		74%	69.5%		78%	22%		86%	31%*		86%	61.5%*

Average Values Eastbound Roadway

	Base	Binder	Top
Roughness Index	200 in/mi	157	132
No. of Deviations	96	25	14
% Defective Length	22%	6	4
Deviation Area	893 in ²	216	156

B. Conventional Construction: Westbound Station 357+0 to 343+80

	INNER LANE						CENTER LANE						OUTER LANE					
	Inner Wheelpath			Outer Wheelpath			Inner Wheelpath			Outer Wheelpath			Inner Wheelpath			Outer Wheelpath		
	Base	Binder	Top	Base	Binder	Top	Base	Binder	Top	Base	Binder	Top	Base	Binder	Top	Base	Binder	Top
Roughness Index(RI)	144	168	119	146	183	108	166	164	127	163	154	100	156	--	129	158	--	131
No. of Deviations(N)	30	29	28	38	19	8	25	22	20	20	13	9	31	--	35	24	--	21
% Improvement(RI)		16.5%*	29%		25%*	41%		1%	22.5%		5.5%	35%		17%			17%	
% Improvement(N)		3%	3%		50%	58%		12%	9%		35%	31%		13%*			12.5%	

Average Values Westbound Roadway

	Base	Binder	Top
Roughness Index	156 in/mi	167	119
No. of Deviations	28	21	20
% Defective Length	6.2%	5.3	5.0
Deviation Area	183 in ²	212	172

*Indicates increase in roughness

roadways, these test sections represent some of the first paving done on the project.

As shown in Table 2, the roughness index of the conventionally placed stabilized base of the westbound roadway ranged from 149 to 166 and averaged 156 inches/mile. In comparison to data obtained on other stabilized base courses constructed in this state, this average roughness value appears to be "typical".

Roughometer data for six sections constructed on the eastbound roadway by the thick lift technique ranged from 178 to 221 and averaged 200 inches/mile. Based on roughometer data then, the thick-lift base was an average of 28% rougher than the conventionally placed base.

The straightedge data of Table 2 indicates a greater relative difference between the roughness of the two roadways: approximately 3-1/2 times more deviations and defective length are associated with the thick-lift paving and 5 times more deviation area.*

*A greater percentage increase in deviation area than in defective length is indicative of an increase in average deviation magnitude. In this case, the "average" deviation in the eastbound roadway has 1-1/2 times greater magnitude than the "average" deviation in the westbound roadway.

The fact that the roughometer and straightedge data differ in the degree of roughness indicated is not a unique result. That is, on relatively rough surfaces, roughness index generally does not increase in direct proportion to straightedge data, but instead gradually approaches some limiting value.

To provide some insight as to the extent to which the contractor was able to overcome any initial difficulties in placing the thick-lift base, an additional mile of straightedge data was collected near the end of the project. Unfortunately, it was not possible to obtain roughometer data for these latter sections.

As shown in Table 3, the later sample shows a significant reduction in all of the straightedge parameters, with the number of deviations and defective length being halved in comparison to the first work and the area of deviations being decreased by 2/3. The greater relative reduction in the deviation area parameter is due to a drastic reduction in the average deviation magnitude, with the number of 1/4" or greater deviations observed in the later work being reduced by 44 to an average of 10 per quarter mile. Only one deviation of 3/8" or greater was observed in the later work.

Table 3. Comparative Straightedge Data:
early and later thick-lift paving

Straightedge Parameter	Data Average for early paving (Sta.340+0)	Data Average for later paving (Sta.397+0)	Percent Reduction
Total number of Deviations	96	50	48%
Number of Deviations of Magnitude $\geq 1/4"$	54	10	81%
Percent Defective Length	22%	11.7%	47%
Area of Deviations	893 in ²	295 in ²	67%

However, while the later thick-lift base has substantially fewer defects than the earlier placed material, even this later work has 80% more deviations than the conventionally placed base.

Figures 1 and 2 are histograms of straightedge data obtained on conventional and thick-lift base (combined early and later work). As shown, the most common surface defect in both types of paving is short (1 or 2') bump or depression of 1/8" magnitude. When the more severe deviations occur, they have a relatively long span length. In the conventional paving, deviations of 1/4" or more almost exclusively occurred near a transverse joint, whereas deviations of this magnitude appear to be randomly distributed throughout the completed thick-lift paving.

FIGURE 1

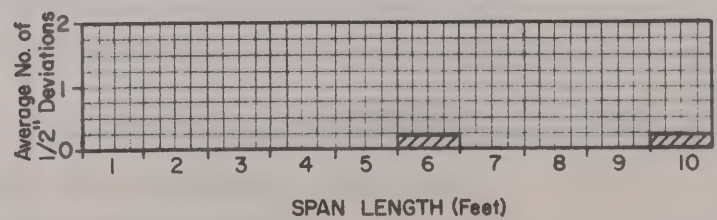
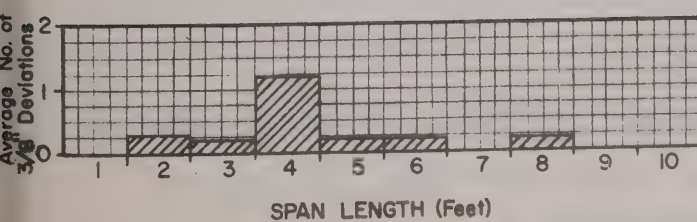
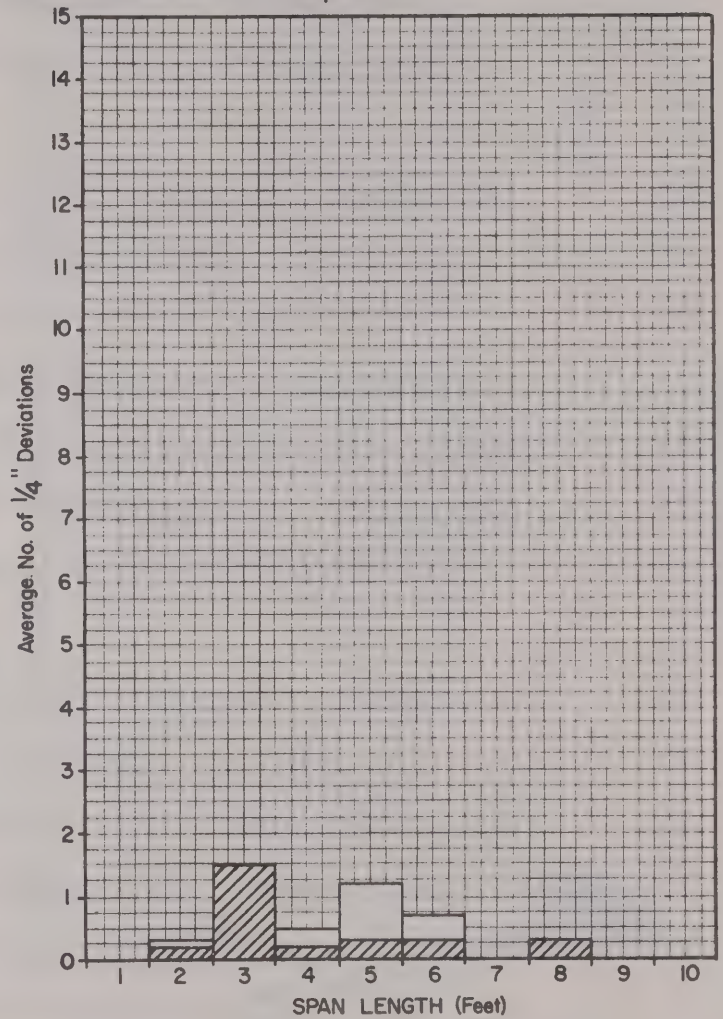
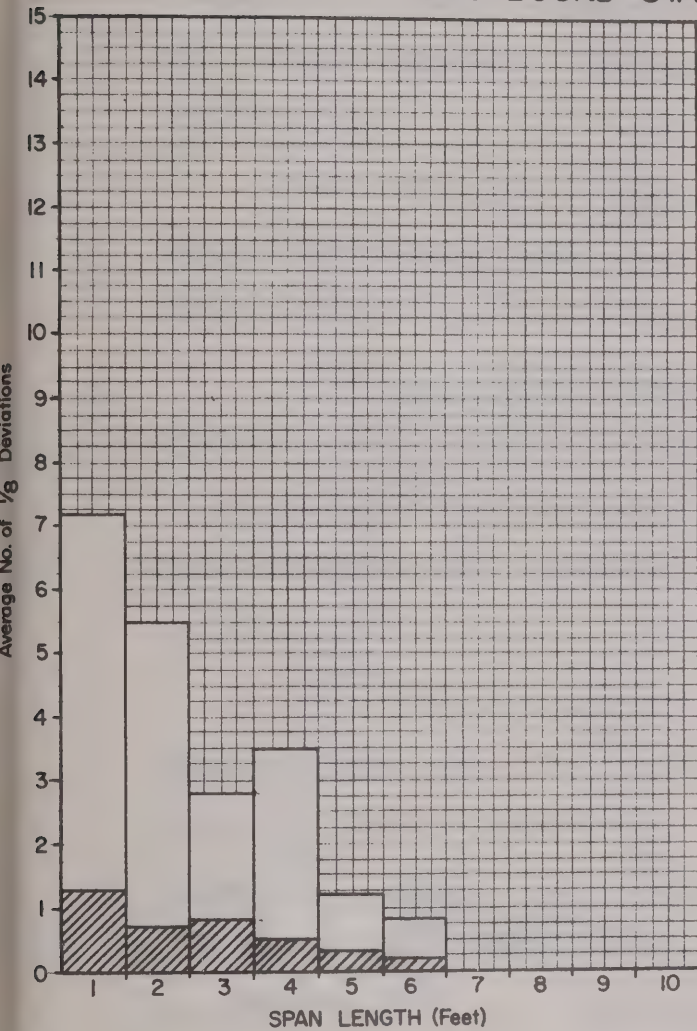
TYPICAL PATTERN OF STRAIGHTEDGE DEVIATIONS

-19-

ROUTE I-80, Pavement Study

KEY FOR LOCATION OF DEVIATION :  = JOINTS  = OTHER

WESTBOUND STAB. BASE (Standard Multiple Lift)



AVERAGE NO. OF DEVIATIONS = 28 (9 @ C.J.)

AVERAGE AREA OF DEVIATIONS = 183 in² (97 in² @ C.J.)

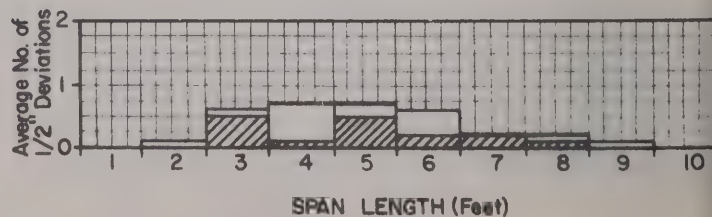
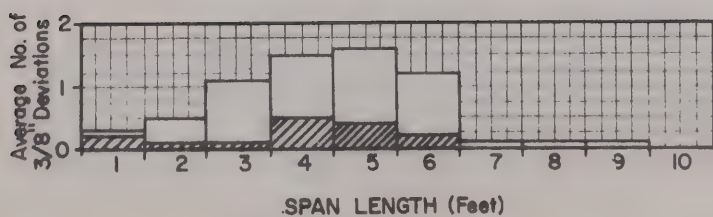
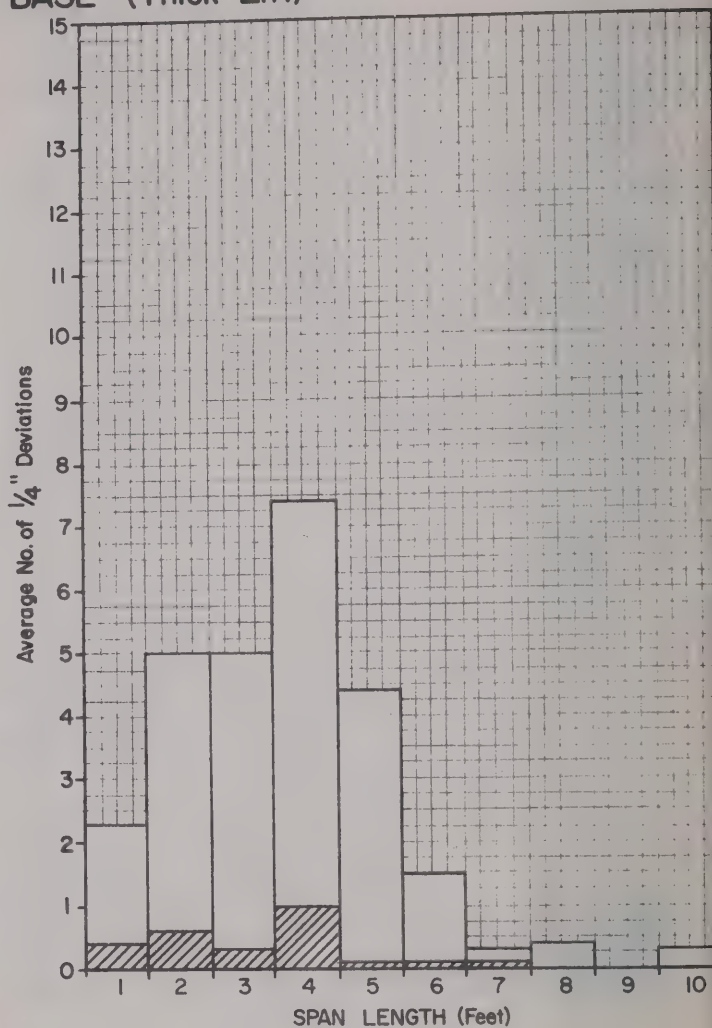
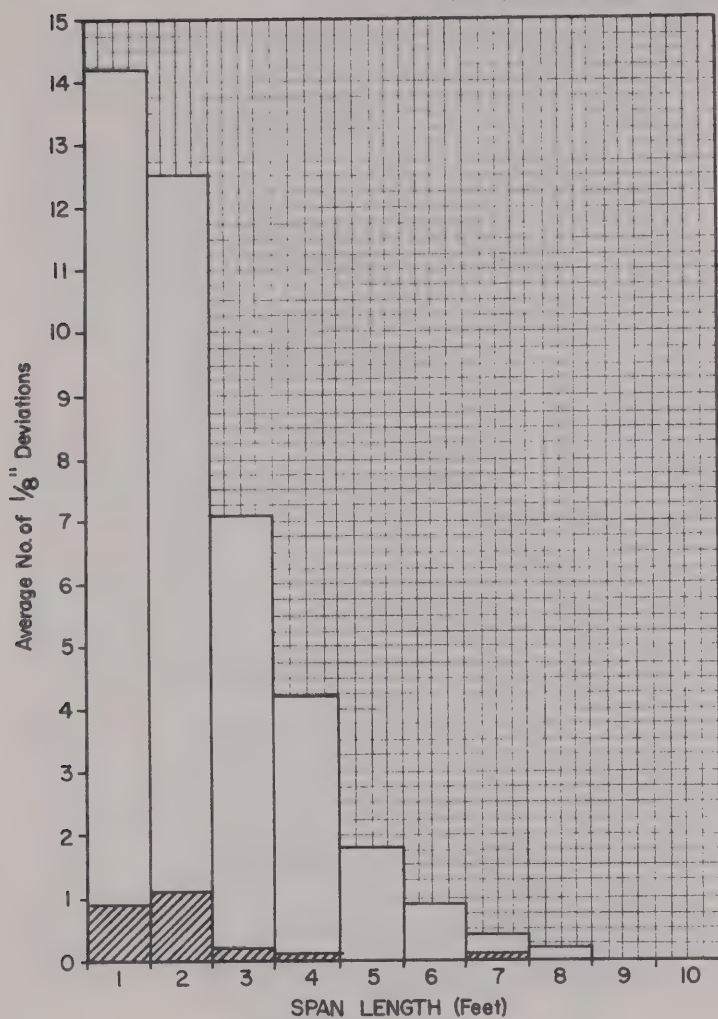
AVERAGE DEFECTIVE LENGTH = 6.2%

TYPICAL PATTERN OF STRAIGHTEDGE DEVIATIONS

ROUTE I-80, Pavement Study

KEY FOR LOCATION OF DEVIATION :  = JOINTS  = OTHER

EASTBOUND STAB. BASE (Thick Lift)



AVERAGE NO. OF DEVIATIONS = 78 (9 @ C.J.)

AVERAGE AREA OF DEVIATIONS = 654 in² (108 in² @ C.J.)

AVERAGE DEFECTIVE LENGTH = 17.9%

B. Binder Course: As shown in Table 2, the roughness index of samples of binder course in the eastbound roadway ranged from 134 to 176 and averaged 157 inches per mile. This binder course thus displayed the same average roughness as the conventionally placed westbound base course. Compared to the underlying thick-lift base, the average roughness for the binder represents a 22% improvement in riding quality.

The straightedge parameters for this eastbound binder show an even greater relative improvement in riding quality; with the number, defective length, and area of deviations all being reduced by 75%.

In contrast, two of four sampled sections of the westbound binder show only a slight (1 to 5%) decrease in roughness index compared to the underlying base, and two show a significant (16 to 25%) increase. On an average basis, a roughness increase of 7% to 167 inches per mile is indicated.

The probable source of this increased roughness is indicated by the straightedge data. That is, while the number and length of deviations decreased, the area of deviations increased by 19%, indicating a general increase in deviation magnitude. More specifically, the westbound binder contained an average of about 12 deviations of 1/4" to 1/2" magnitude per quarter mile: about 5 more than the underlying base.

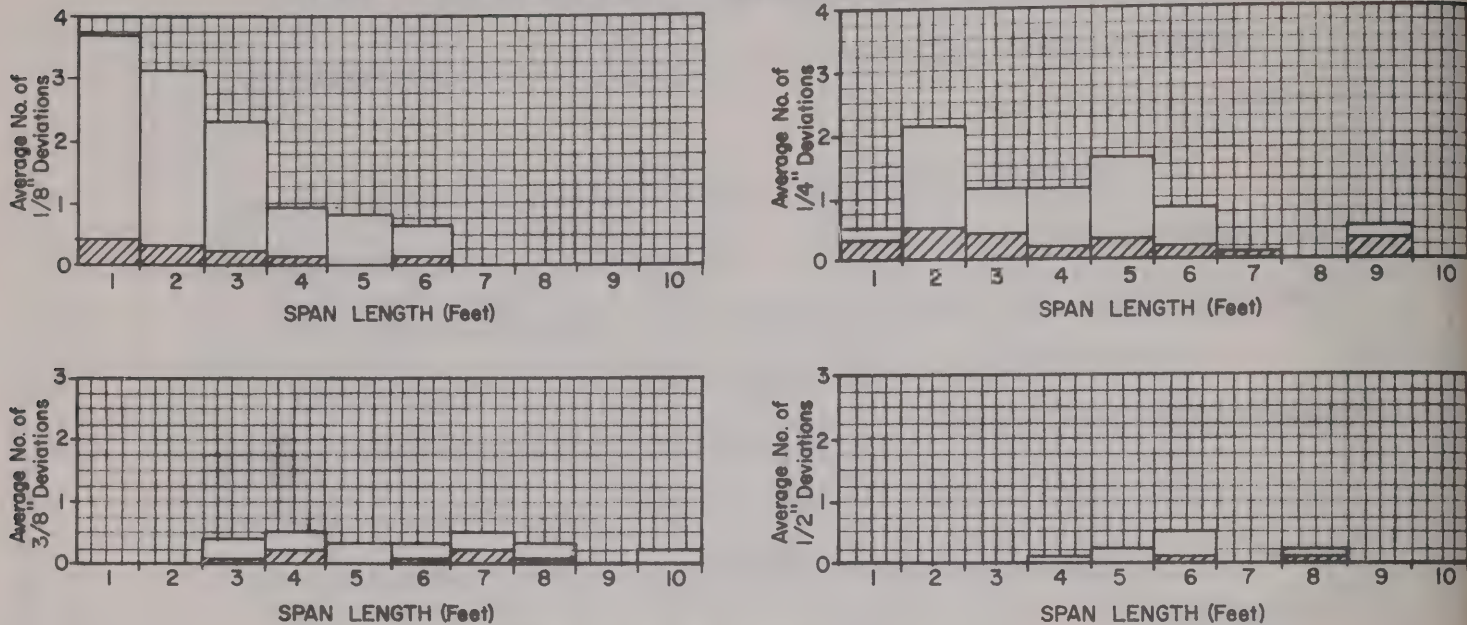
An examination of the comparative straightedge data of Figures 3 and 4 reveals that a very similar pattern of surface defects exists for the east and westbound roadway binder courses. Further, the calculated deviation area parameters are almost identical (228 in² EB vs 212 in² WB). The straightedge data thus corroborates the roughometer data indication that only small difference exists between the roughness of the binder course in the two roadways.

TYPICAL PATTERN OF STRAIGHTEDGE DEVIATIONS

ROUTE I-80, Pavement Study

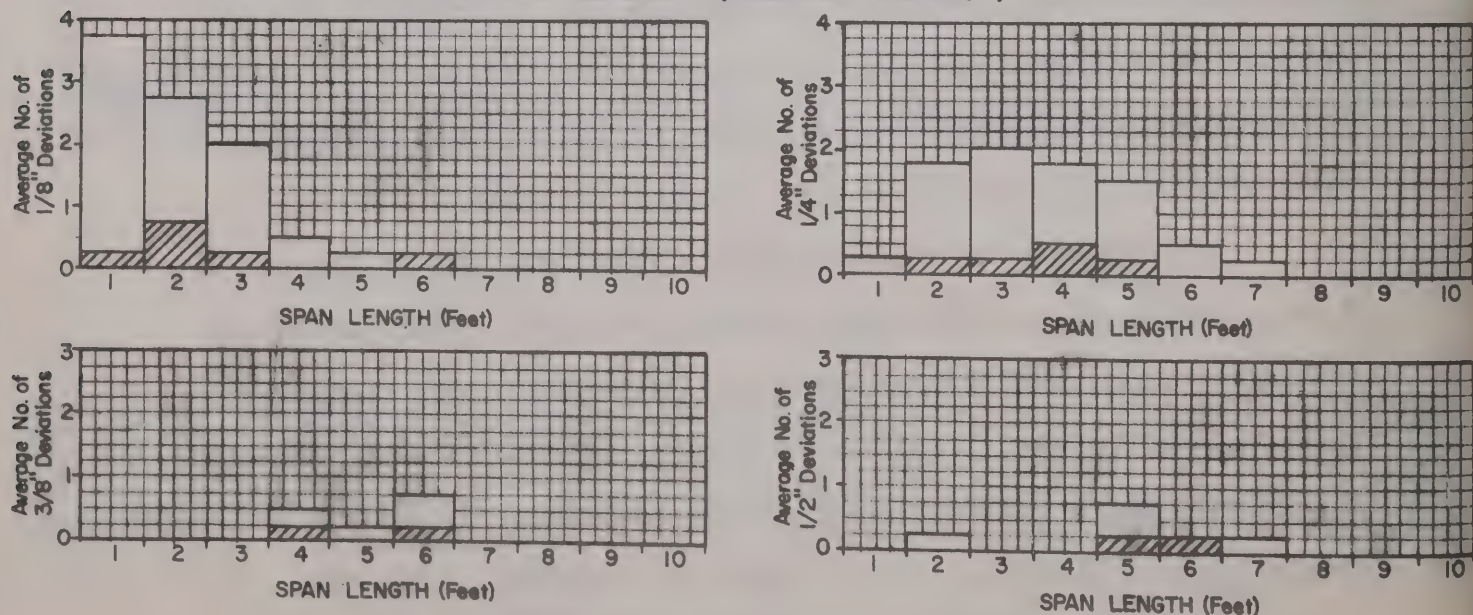
KEY FOR LOCATION OF DEVIATION:  = JOINTS  = OTHER

FIGURE 3 EAST BOUND BINDER (Automatic Control)



AVERAGE NO. OF DEVIATIONS = 23 (4 @ C.J.)
 AVERAGE AREA OF DEVIATIONS = 228 in² (56 in² @ C.J.)
 AVERAGE DEFECTIVE LENGTH = 5.9%

FIGURE 4 WEST BOUND BINDER (Manual Control)



AVERAGE NO. OF DEVIATIONS = 21 (4 @ C.J.)
 AVERAGE AREA OF DEVIATIONS = 212 in² (48 in² @ C.J.)
 AVERAGE DEFECTIVE LENGTH = 5.3%

C. Top Course: From approximately equal levels of roughness on the binder course, the roughness of the finished pavement sample shown in Table 2 was reduced by an average of 16% to 132 inches/mile in the eastbound roadway, while that of the westbound was reduced by an average of 29% to 119 inches/mile. In this particular sample then, a lesser reduction in roughness was observed for top course placed using automatic grade controls than for that placed manually.

Roughometer data for the finished surface of the entire project is presented in Table 4. From this tabulation, it is apparent that the preceding discussed data of Table 2 (the first eastbound 1/4 mile in Table 4) is significantly rougher than the remainder of the eastbound pavement. However, regardless of whether this first paving is included, the average roughness index of the two roadways remain almost identical (113 EB vs 111 in/mi. WB). In comparison to the FHWA roughometer criteria, the riding quality finally achieved on both roadways would be rated as "Poor".

The average pattern of straightedge defects observed for 18 samples of finished surface on the westbound roadway and 10 sections in the eastbound are shown in Figures 5 and 6*.

On an average basis, this straightedge data shows remarkable agreement with the roughometer data, the pattern of defects for the east and westbound roadways being almost identical.

If the surface tolerances of the FHWA guide Specifications were applied to the straightedge data for the finished pavement, a 20% payment penalty would be indicated.

*Straightedge data for all courses is summarized in simplified form in Appendix Figure A1.

Table 4: Top Course Roughometer Data, Route I-80, Section 1M

Eastbound Roadway

(beginning at Sation 344+0)

Location	<u>Inner Lane</u>		<u>Center Lane</u>		<u>Outer Lane</u>	
	<u>Inner W.P.</u>	<u>Outer W.P.</u>	<u>Inner W.P.</u>	<u>Outer W.P.</u>	<u>Inner W.P.</u>	<u>Outer W.P.</u>
0 to .25 mi.	140 in/mi.	134 in/mi.	117 in/mi.	134 in/mi.	131 in/mi.	137 in/mi.
.25 to .50	130	110	103	80	102	135
*.50 to .75	112	112	122	118	101	98
.75 to 1.00	107	111	102	103	93	106
1.00 to 1.25	125	124	105	108	104	114
1.25 to 1.50	117	105	103	118	109	112
Average	123	116	109	110	107	117

Eastbound Avg. 113 inches/mile

Westbound Roadway

(beginning at Station 410+30)

0 to .25 mi.	94 in/mi.	105 in/mi.	112 in/mi.	117 in/mi.	117 in/mi.	116 in/mi.
.25 to .50	135	121	103	116	102	107
.50 to .75	118	103	117	104	113	88
*.75 to 1.00	110	100	122	114	115	112
1.00 to 1.25	115	104	125	104	124	90
1.25 to 1.50	119	108	127	100	129	131
Average	115	107	118	109	117	107

Westbound Avg. 111 inches/mile

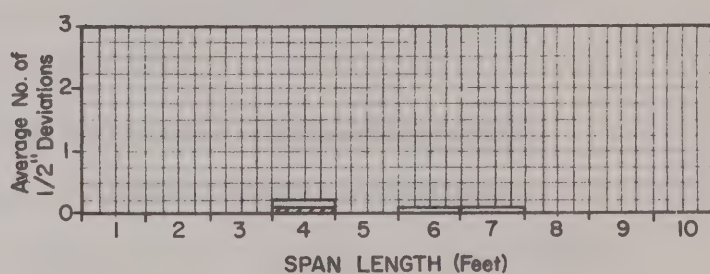
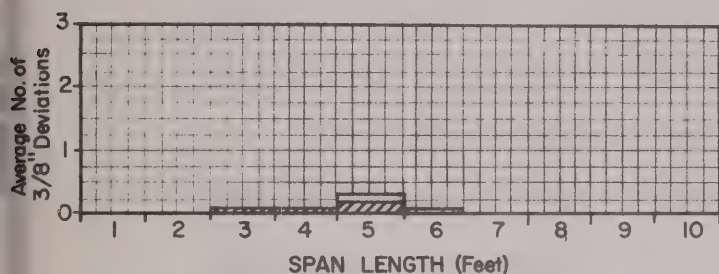
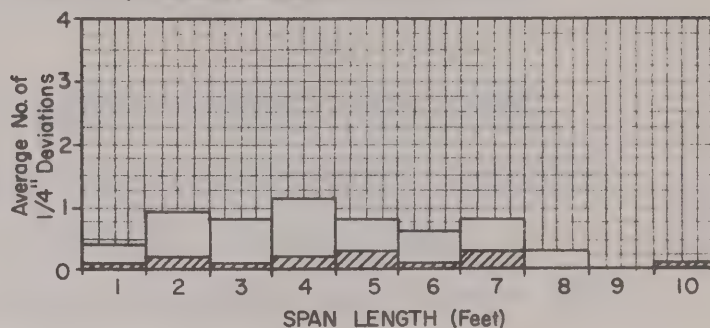
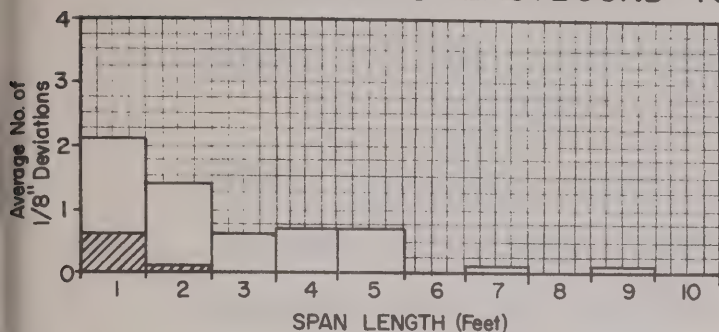
*Reading adjusted to eliminate bridge roughness

TYPICAL PATTERN OF STRAIGHTEDGE DEVIATIONS

ROUTE I-80, Pavement Study

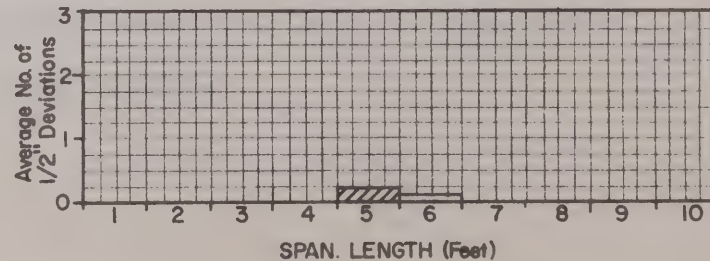
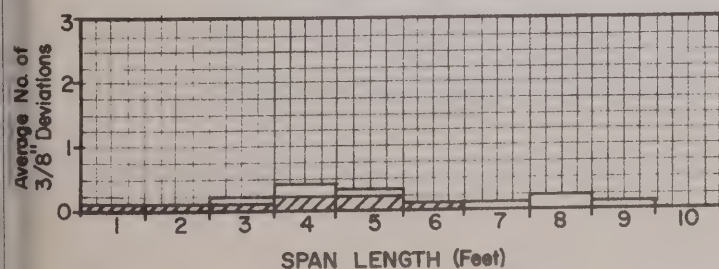
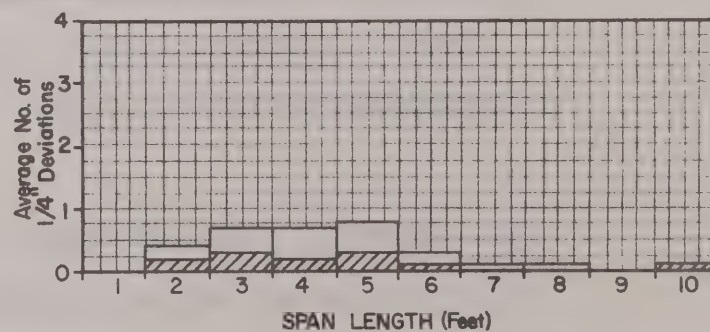
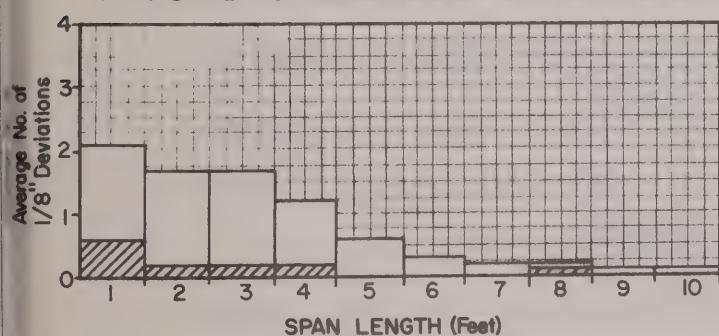
KEY FOR LOCATION OF DEVIATION:  = JOINTS  = OTHER

FIGURE 5 EASTBOUND TOP CRSE. (Automatic Control)



AVERAGE NO. OF DEVIATIONS = 13 (3 @ C.J.)
 AVERAGE AREA OF DEVIATIONS = 128 in² (35 in² @ C.J.)
 AVERAGE DEFECTIVE LENGTH = 3.4%

FIGURE 6 WESTBOUND TOP CRSE. (Manual Control)



AVERAGE NO. OF DEVIATIONS = 13 (3 @ C.J.)
 AVERAGE AREA OF DEVIATIONS = 116 in² (35 in² @ C.J.)
 AVERAGE DEFECTIVE LENGTH = 3.5%

The percent defective length for both roadways (3.4 EB and 3.5 WB) borders the "removed and replace" criteria of this FHWA specification (3.5+ percent defective).

VI. Conclusions:

1. As expected, the thick-lift mode of construction produced significantly higher bituminous base course densities than the standard multiple-lift paving method. Also, the degree of uniformity of density within the base was found to be at least equivalent to that generally achieved in standard construction.

2. The Department's normal compaction sequence (1 pass 3-wheel roller, tandem finish rolling) can successfully produce adequate densities in a four-inch thickness of stone mix, bituminous stabilized base. Accordingly, the thick-lift paving of a four inch base course requires **one** half of the compaction effort needed in compacting the same thickness of base constructed by normal multiple-lift methods.

3. It was expected that production rates for the single-thick lift paving would be nearly twice that of the double-lift operation. Unfortunately no production increase whatsoever was achieved. The primary reason for a lack of production improvement was the failure of material supply rates to be appropriately increased for the single-lift paving. If this condition is typical -- i.e. production increases are limited by material supply rather than by construction techniques -- merely permitting the use of the thick-lift technique would not be expected to result in lower bid prices.

4. Rolling straightedge and roughometer data obtained on this project show good agreement, and both indicate that the average level of riding quality achieved on the finished pavement of the test and control roadways are identical and merit a "poor" rating.

5. It can be expected that bituminous stabilized base course placed in a single-lift will be significantly rougher than that placed in two or more lifts, even when such thick-lift paving is accomplished using a paver equipped with a ski reference automatic grade control. On this project, single-lift base course placed using automatic grade controls contained an average of as much as 3-1/2 times more straightedge deviations than conventionally placed base. This increase in surface defects translated as about a 25% to 30% greater roughness index for the thick-lift base.

6. It is a truism that a superiority in one construction input--men, materials or equipment--may not compensate for a deficiency in one of the other inputs. Thus, on this project, the mere provision of a paver equipped with automatic grade controls did not result in an improved or acceptable level of riding quality.

7. The rolling straightedge provided rapid and valuable roughness data to State construction personnel who were very actively attempting to assist the contractor in improving riding quality throughout the course of the work.

8. Based on the results obtained to-date in a current research project, it appears that the riding quality of New Jersey bituminous pavements are generally in need of improvement. The application of automatic grade control systems to the placement of bituminous pavement courses--including conventional multiple-lift base construction--holds promise for improving this situation.

If the work of the present contractor can be considered as typical, the needed general improvement in riding quality can be expected to be particularly difficult to achieve on those pavements constructed by the thick-lift technique.

One factor which might help minimize this effect is the use of a high-type grade reference system in placing thick-lift base (i.e., an erected stringline). Again, however, if this high-type reference were used in conjunction with multiple-lift construction, an even better riding quality should result.

VII. Closing Comments and Recommendations:

The results of this study indicate that the riding quality of bituminous stabilized base course will suffer if thick-lift rather than conventional multiple-lift construction methods are employed. A significant factor contributing to this greater relative roughness is the fact that a basically stop-and-go operation and allied surface defects result when the greater material demands of thick-lift paving aggravate the normally difficult problem of achieving coordination between material supply and paver speed.

In view of the higher densities obtainable, the potential for cost reduction, and the fact that a final (top course) surface having riding quality approximately equal to that of conventional multiple-lift construction can be obtained even when a less than optimum automatic grade reference system is used, it is the consensus of the Equipment Committee that riding quality considerations should not preclude the future use of the thick-lift paving technique in New Jersey. However, in the absence of an established and enforced riding quality acceptance provision, it is felt that future thick-lift projects should include a process control specification provision that would minimize the potential for greater relative roughness on single-lift construction. This could be accomplished by requiring a minimum rate of material supply. Such a provision conceivably would not only minimize intermittency of paving, but also would maximize the possibility of achieving cost reduction.

It is, therefore, recommended that thick-lift bituminous stabilized base course construction be permitted with the following reservations:

- (1) The maximum permitted lift thickness should be approximately four inches.
- (2) The use of thick-lift construction should be restricted to stone-mix base.
- (3) Paving should be accomplished by pavers equipped with automatic grade control referenced from an erected stringline.
- (4) A minimum rate of supply and placement of 180 tons per hour should be required. (This rate is consistent with a continuous forward motion of the paver of approximately 15 fpm and an 80% efficient 2-1/2 ton asphalt plant).

VIII. Suggested Future Studies:

The following suggestions for possible future thick-lift paving studies by the Equipment Committee are presented for consideration:

1. Determine the suitability of placing gravel mix bituminous stabilized base by the thick-lift technique.
2. Monitor future thick-lift projects and/or undertake a separate study to determine the grade reference system or systems that will provide an "optimum" solution to the problem of obtaining a desirable riding quality level for particular project conditions. For example, the use of an erected stringline reference for base course construction followed by a ski reference for subsequent binder and top courses might prove more effective than exclusive reliance on an erected stringline.

APPENDIX

Page

Figure A-1, Typical Pattern of Straightedge Deviations..... 33

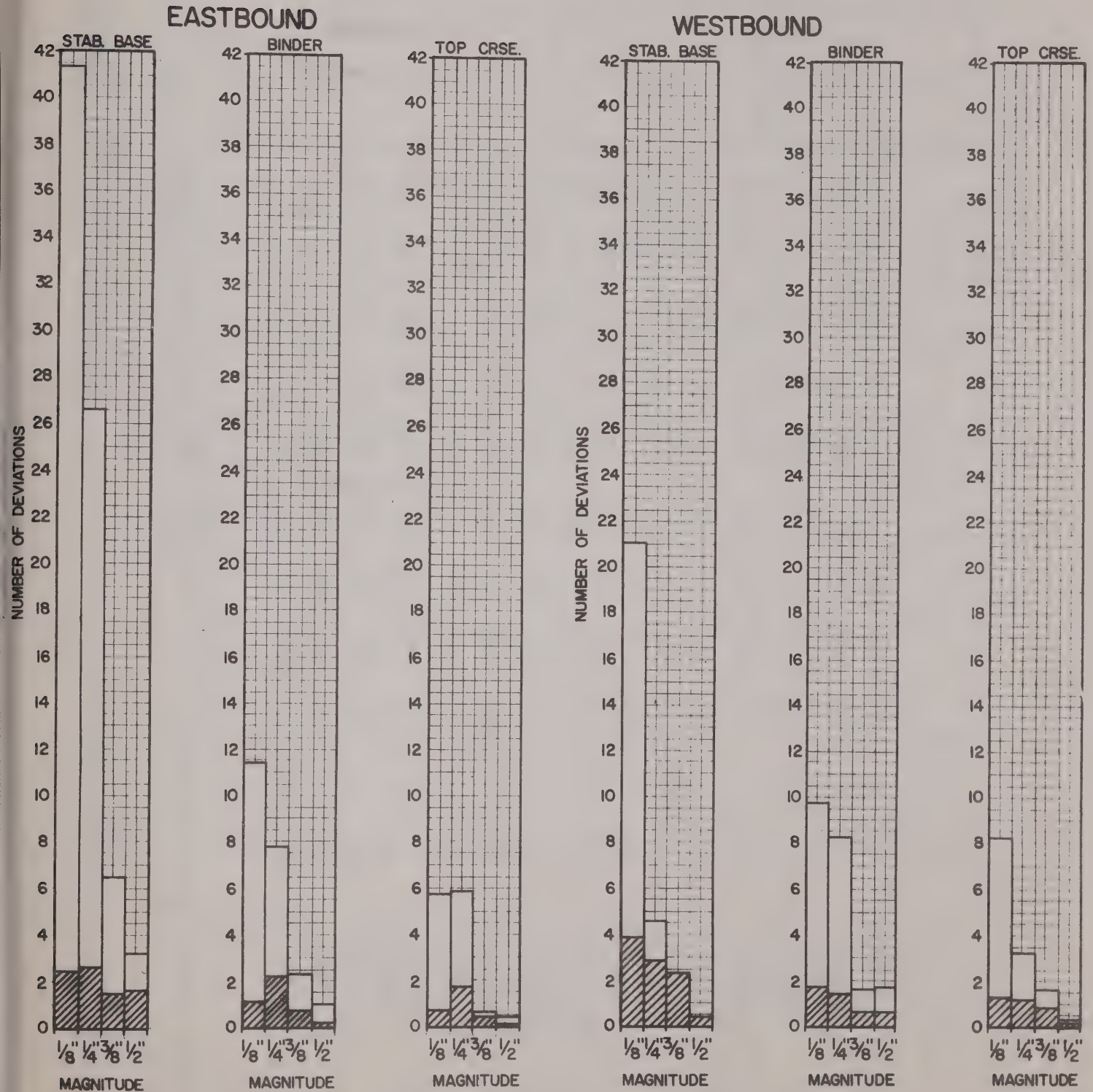
Table A-1, Specific Gravity and Void Content of Bituminous
Concrete Cores..... 34 to 38

FIGURE I-A

TYPICAL PATTERN OF STRAIGHTEDGE DEVIATIONS

ROUTE I-80, Pavement Study

KEY FOR LOCATION OF DEVIATION :  = JOINTS  = OTHER



EXPERIMENTAL COMPACTION PROJECT

Type: ~~Mix~~ #1 (Stone)

Contractor: **Franklin Constr. & Tri-County Asphalt Corp., - Roseland, N. J.**

Maximum Specific Gravity
by Solvent Immersion
(By Lift) (Combined)

Contractor: Franklin Constr. Co. & Tri-County Asphalt Corp., - Roseland, N. J.

				Full			Upper Half of			Lower Half of			Mix No.			REMARKS	
Core Number	Station	Date Cut		Thick-ness	Specific Gravity	% Voids	Thick-ness	Specific Gravity	% Voids	Thick-ness	Specific Gravity	% Voids	Thick-ness	Specific Gravity	% Voids	Maximum Specific Gravity (γ_m) (Combined)	
D 1283	B 380/78 ML EB R1	10-23-70		4.7	2.39	6.3	2.3	2.37	7.0	2.4	2.38	6.7				Upper = 2.54 2.54	
D 1284	B 383/30 " " " "	"		3.9	2.28	10.2	1.8	2.23	12.2	2.1	2.26	11.4				Lower = 2.55	
D 1285	B 386/06 " " R2	"		4.2	2.41	5.5	1.9	2.40	5.9	2.3	2.40	5.9					
D 1286	B 389/42 " " B3	"		4.1	2.38	6.7	2.1	2.33	8.6	2.0	2.36	7.4					
D 1287	B 392/16 " " R1	"		4.3	2.36	7.4	1.9	2.29	10.2	2.3	2.33	8.6					
D 1288	B 395/33 " " " "	"		4.6	2.37	7.0	2.1	2.34	8.2	2.3	2.34	8.2					
D 1289	B 397/40 " " R2	"		3.7	2.36	6.3	1.9	2.34	7.5	1.8	2.33	6.8				Upper = 2.53 2.52	
D 1290	B 399/76 " " " "	"		3.7	2.43	4.7	1.9	2.41	5.5	2.0	2.39	6.3					
D 1291	B 401/78 " " B3	"		4.4	2.40	5.9	2.2	2.38	6.7	2.2	2.38	6.7					
D 1292	B 404/27 " " R1	"		5.0	2.39	6.3	2.5	2.38	6.7	2.5	2.34	6.2					
D 1293	B 406/40 " " " "	10-27-70		4.7	2.38	6.7	2.4	2.34	8.2	2.3	2.34	8.2				Upper = 2.56 2.55	
D 1294	B 410/40 " " " "	"		4.4	2.44	4.3	2.2	2.43	4.7	2.2	2.41	5.5					
D 1295	B 413/07 " " " "	"		4.6	2.37	7.0	2.3	2.35	8.2	2.3	2.33	8.6					
D 1296	B 415/96 " " B3	"		6.6	2.42	5.1	3.3	2.42	5.1	3.3	2.39	6.3					
D 1297	B 417/ ML EB " "	10-23-70		7.0	2.38	6.7	3.5	2.40	5.9	3.5	2.33	8.6					
D 1298	B 418/57 " " " "	"		4.1	2.42	4.7	2.0	2.37	6.7	2.1	2.37	6.7				Upper = 2.54 2.54	
D 1299	B 421/99 " " " "	"		4.5	2.43	4.7	2.2	2.43	4.7	2.2	2.41	5.5					

Job: Rt. 80 Sec. 14

Type: Hx #1 (Stone)

Producer: Tri-County Asphalt Co., - Rockaway, New Jersey

Contractor: Franklin Constr. & Tri-County Asphalt Co., - Roseland, N. J.

Core Number	Station	Date Cut	Full Mix No.			Upper half of Core 1			Lower half of Core 1			Mix No.			REMARKS
			Thick-ness	Specific Gravity	% Voids	Thick-ness	Specific Gravity	% Voids	Thick-ness	Specific Gravity	% Voids	Thick-ness	Specific Gravity	% Voids	
D 1300	B 423/60 AL ED R1	10-23-70	4.4	2.42	5.1	2.2	2.42	5.1	2.2	2.41	5.5				
D 1301	B 429/82 " " R2	"	4.2	2.45	3.9	2.0	2.45	3.9	2.2	2.44	4.3				
D 1302	B 432/65 " " "	"	3.2	2.41	5.5	1.5	2.38	6.7	1.6	2.40	5.9				
D 1303	B 435/79 " " R1	"	3.9	2.47	3.1	1.9	2.42	5.1	2.0	2.45	4.3				Upper = 2.55 2.55
D 1304	D 437/10 " " "	"	4.1	2.34	6.2	2.0	2.34	6.2	2.1	2.30	7.0				Lower = 2.56
D 1305	B 438/58 " " R2	"	4.1	2.36	6.7	2.0	2.35	7.0	2.1	2.32	7.0				
D 1352	B 421/72 " " "	10-27-70	4.3	2.29	10.2	2.3	2.28	10.6	2.0	2.23	12.5				
D 1353	B 404/55 " " R1	"	4.0	2.41	5.5	2.0	2.37	6.3	2.0	2.41	5.5				
D 1306	B 433/51 " " R3	10-26-70	-	-	-	-	-	-	-	-	-				No mix 1 on this core.
D 1307	B 434/37 " " R2	"	-	-	-	-	-	-	-	-	-				No mix 1 on this core.
D 1308	B 434/77 " " "	"	4.3	2.34	6.6	2.0	2.30	1.2	2.3	2.34	6.6				Upper = 2.56 2.56 Lower = 2.56
D 1309	B 433/68 " " R3	"	4.4	2.31	9.4	2.1	2.30	6.6	2.3	2.28	10.6				
D 1310	B 430/10 " " R1	"	4.0	2.34	6.2	1.9	2.32	7.0	2.1	2.33	8.6				
D 1311	B 429/15 " " R2	"	-	-	-	-	-	-	-	-	-				No mix 1 on this core.
D 1312	B 423/17 " " R1	"	2.9	2.32	9.7	1.5	2.30	10.2	1.4	2.32	9.7				Upper = 2.56 2.57 Lower = 2.57
D 1313	B 422/10 " " "	"	3.6	2.31	9.4	1.6	2.28	10.6	1.0	2.31	9.4				
D 1314	B 422/68 " " R2	"	4.0	2.34	6.2	2.0	2.32	7.0	2.0	2.27	11.0				
D 1315	B 417/56 " " R1	"	4.8	2.36	7.4	2.0	2.37	7.0	2.3	2.33	8.6				
D 1316	B 417/52 AL " "	"	3.6	2.33	6.6	1.5	2.27	10.2	2.1	2.34	6.2				
D 1317	B 414/31 " " R3	"	4.0	2.37	7.8	2.0	2.33	6.6	2.0	2.32	10.4				Upper = 2.55 2.57 Lower = 2.55

Job: Rt. 20 Sec. 1M

Type: Mix #1 (Stone)

Producer: Tri-County Asphalt Co., Rockaway, N.J.

Contractor: **Franklin Constr. & Tri-County Co., - Roseland, N.J.**

[illegible]

Mlx #1 (Stone)

Contractor: Franklin Constr. & Tri-County Asphalt Co., - Roseland, N.J.

						CONCRECTION												
						Full Depth Mix No. 1			Upper Half of Core Mix No. 1			Lower Half of Core Mix No. 1			Mix No.			REMARKS
Core Number	Station		Date Cut	Thick-ness	Specific Gravity	% Voids	Thick-ness	Specific Gravity	% Voids	Thick-ness	Specific Gravity	% Voids	Thick-ness	Specific Gravity	% Voids			
D 1335	B	370/23 ML WB R2	10-26-70	4.5	2.36	7.4	2.4	2.37	7.0	2.1	2.34	8.2						
D 1336	B	361/73 " 2" "	"	3.7	2.34	8.9	1.8	2.35	8.6	1.9	2.27	11.7						Upper - 2.57 Lower - 2.57 2.57
D 1337	B	365/33 " " R3	"	3.8	2.34	8.2	1.8	2.28	10.6	2.0	2.38	6.7						
D 1338	B	363/11 " " R1	"	3.5	2.32	9.0	2.0	2.34	8.2	1.5	2.26	11.4						
D 1339	B	361/96 " " L1	"	4.6	2.35	7.8	2.3	2.34	8.2	2.3	2.33	8.6						
D 1340	B	359/00 " " L1	"	3.8	2.34	8.2	1.9	2.31	9.4	1.9	2.35	7.8						
D 1341	B	356/54 " " "	"	3.8	2.32	8.3	1.9	2.31	9.0	1.9	2.31	9.0						Upper - 2.54 Lower - 2.54 2.54
D 1342	B	354/46 " " L2	"	4.3	2.34	8.2	2.1	2.33	8.6	2.2	2.32	9.0						
D 1343	B	352/56 " " L3	"	4.3	2.38	6.7	1.8	2.36	7.4	2.5	2.39	6.3						
D 1344	B	356/01 " " "	"	4.4	2.38	6.7	2.4	2.37	7.0	2.0	2.38	6.7						
D 1345	B	347/49 " " L2	"	4.7	2.34	8.2	2.6	2.34	8.2	2.1	2.33	8.6						
D 1346	B	345/12 " " "	"	4.9	2.35	8.2	2.6	2.35	7.8	2.3	2.32	9.4						Upper - 2.51 Lower - 2.56 2.56
D 1347	B	341/57 " " "	"	4.2	2.35	7.8	2.1	2.32	7.0	2.0	2.37	7.0						
D 1348	B	340/15 " " "	"	4.5	2.33	8.6	2.3	2.34	8.2	2.2	2.30	9.8						
D 1349	B	337/03 " " "	"	4.8	2.39	6.3	2.3	2.39	6.3	2.5	2.38	6.7						
D 1350	B	336/90 " " L3	"	3.8	2.32	9.0	1.7	2.30	9.8	2.1	2.31	9.4						
	Averages				4.2	2.37	6.9	2.1	2.36	7.6	2.1	2.35	8.0					
	LBS/SY/in. Thick				110.9			110.4			110.0							

